Parallel Preconditioning for Block-Structured CF Problems

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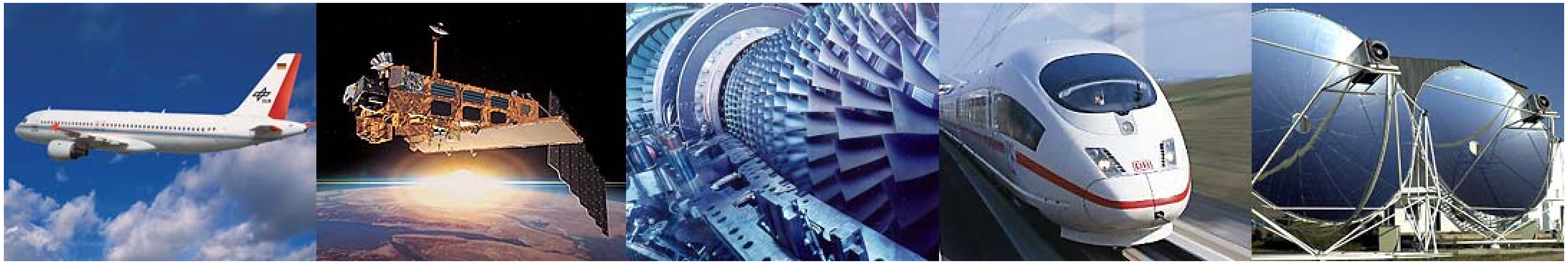


- Research Institution
- Space Agency
- Project Management Agency


DLR

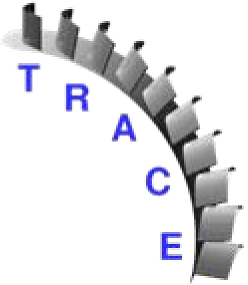
Locations and employees

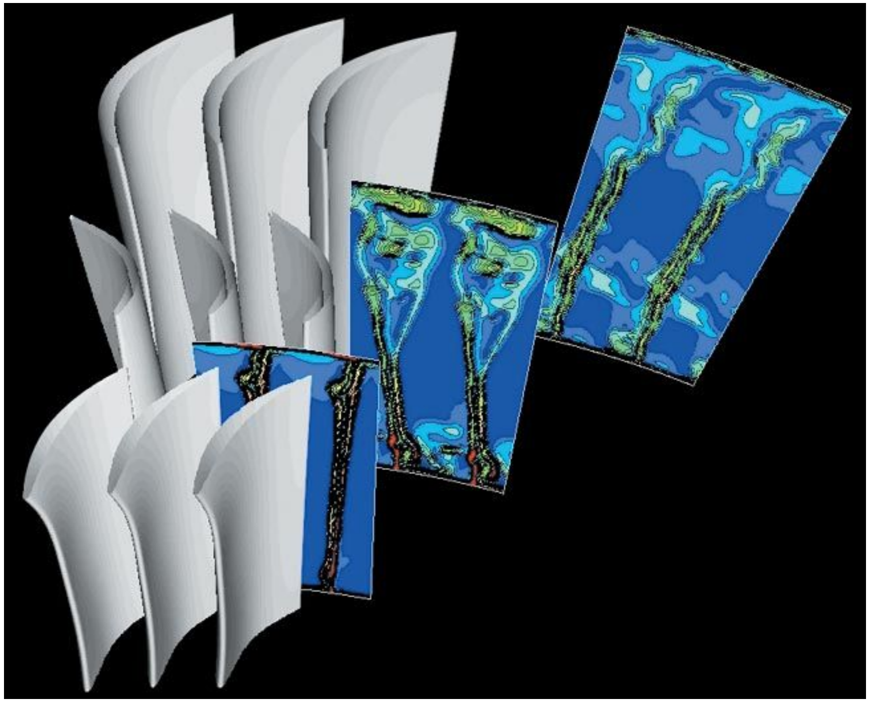
Germany: 6000 employees across 29 research institutes and facilities at

- 13 sites.

Offices in **Brussels**, **Paris** and **Washington**.

Parallel Simulation System TRACE



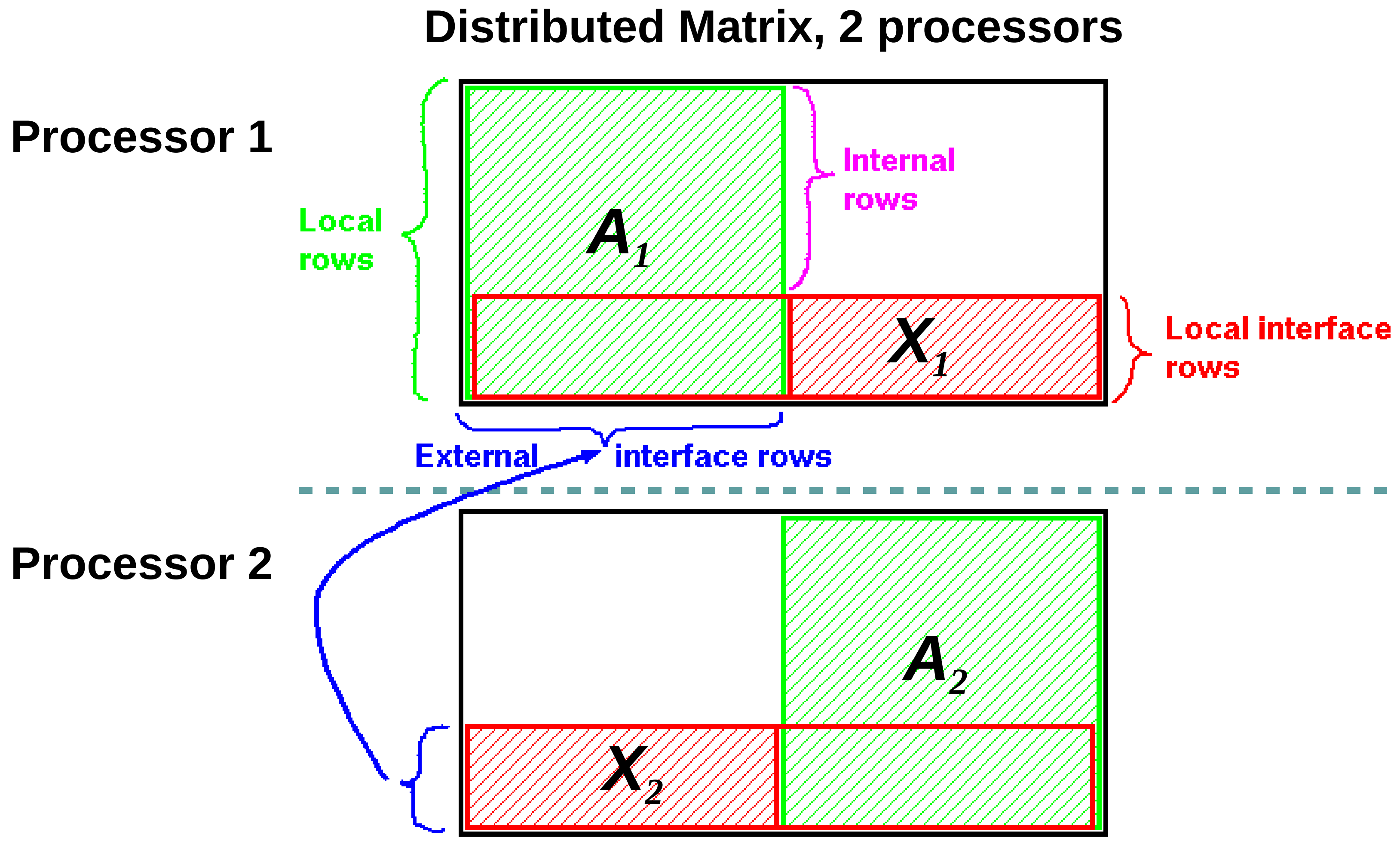


- TRACE: Turbo-machinery Research Aerodynamic Computational Environment
- Developed by the Institute for Propulsion Technology of the German Aerospace Center (DLR-AT)
- Calculates internal turbo-machinery flows
- Finite volume method with block-structured grids
- The linearized TRACE modules require the parallel, iterative solution of large, sparse non-symmetric systems of linear equations.

Preconditioners for TRACE: Background

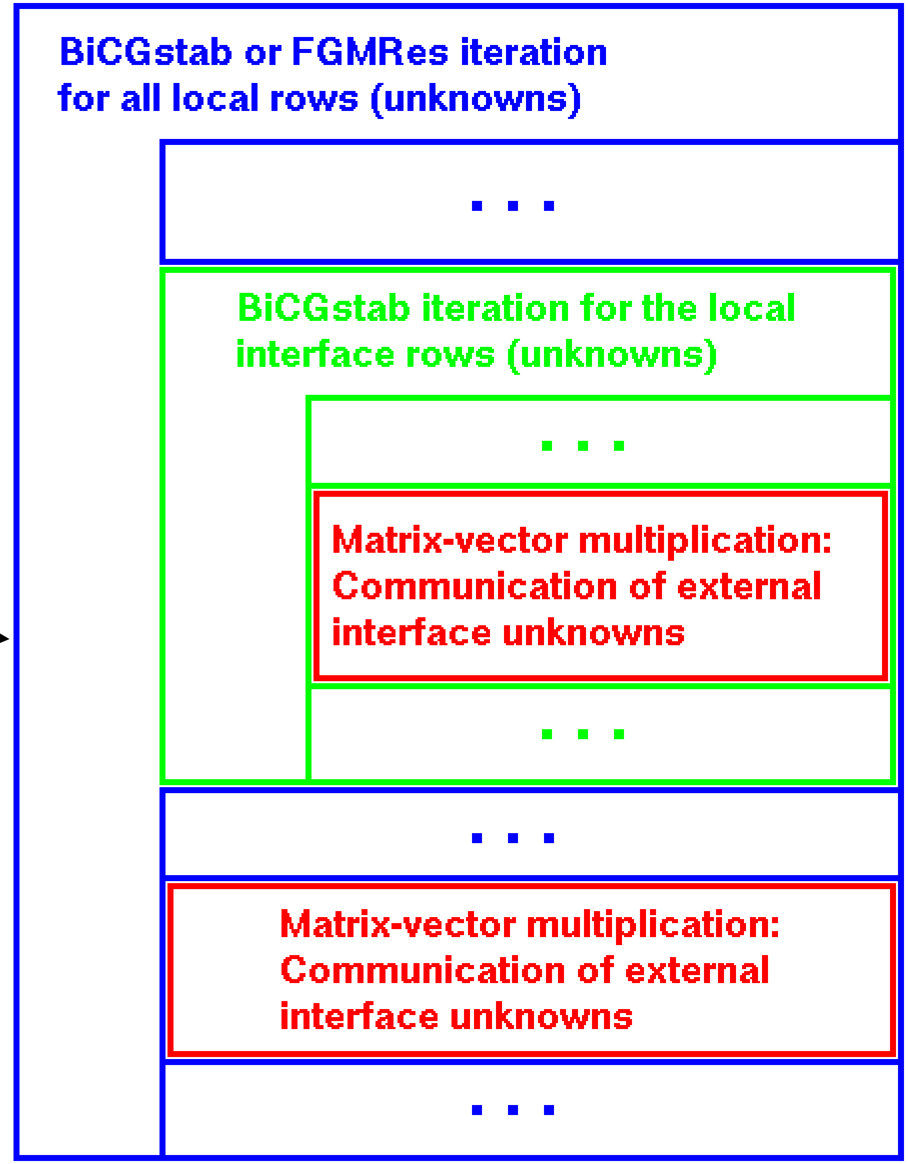
- Modules linearTRACE or adjointTRACE $Ax = b$
  - A non-symmetric, complex or real, sparse
  - Parallel iterative solver: (F)GMRes with preconditioning $P^{-1}Ax = P^{-1}b$
    - Distinctly dominates the time behavior
    - Matrix-vector and vector-vector operations
    - Preconditioning usually is the most time-consuming operation
      - Crucial for scalability
      - Status: Block-local preconditioning
        - ILU, SSOR
        - Scalability limited
      - Goal: global, scalable preconditioner
        - Experiments with Distributed Schur Complement (DSC) methods

DSC Method: Definitions

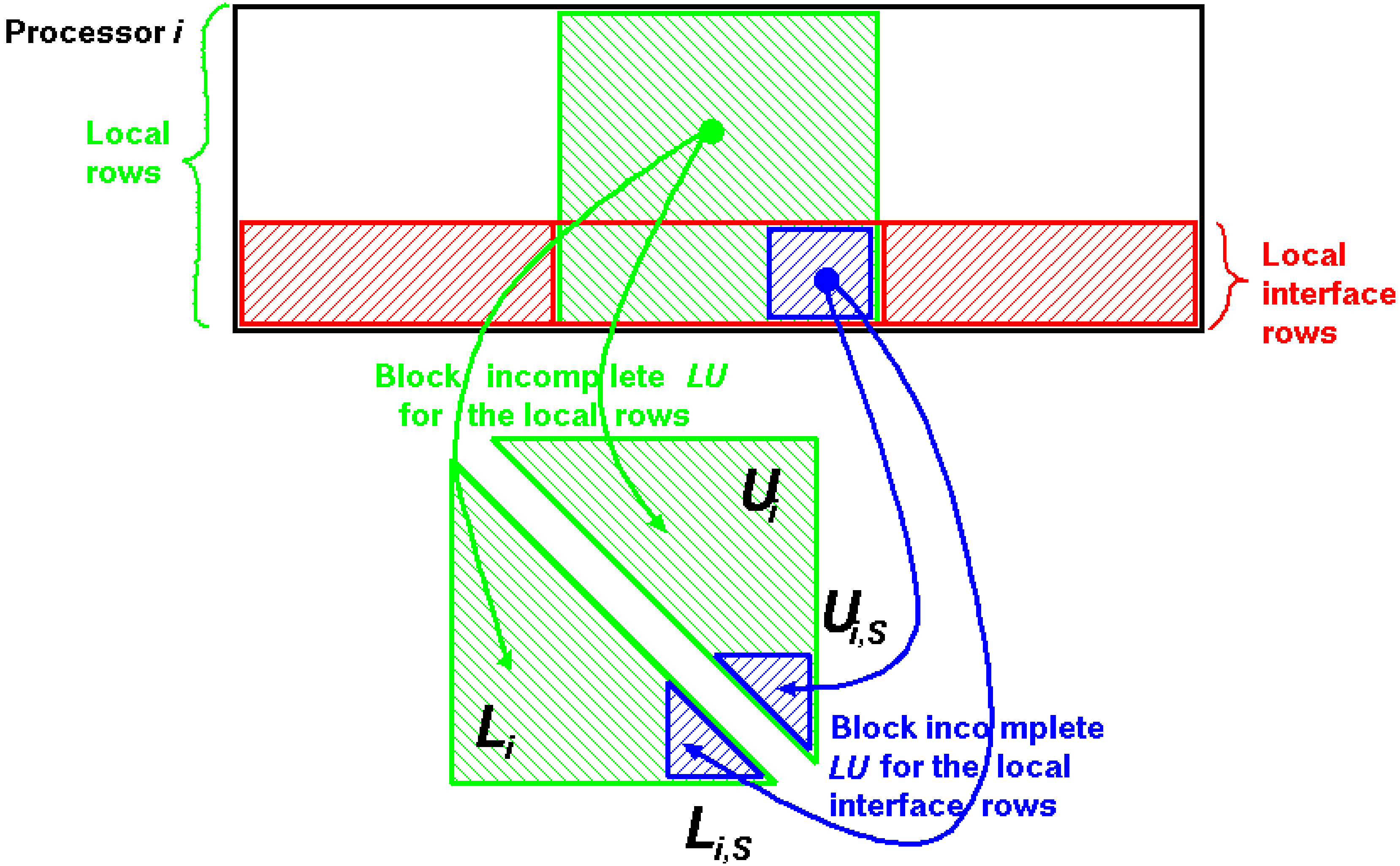


DSC Methode: Algorithm

Schematic view on each processor



DSC Method: Incomplete *LU* Factorizations

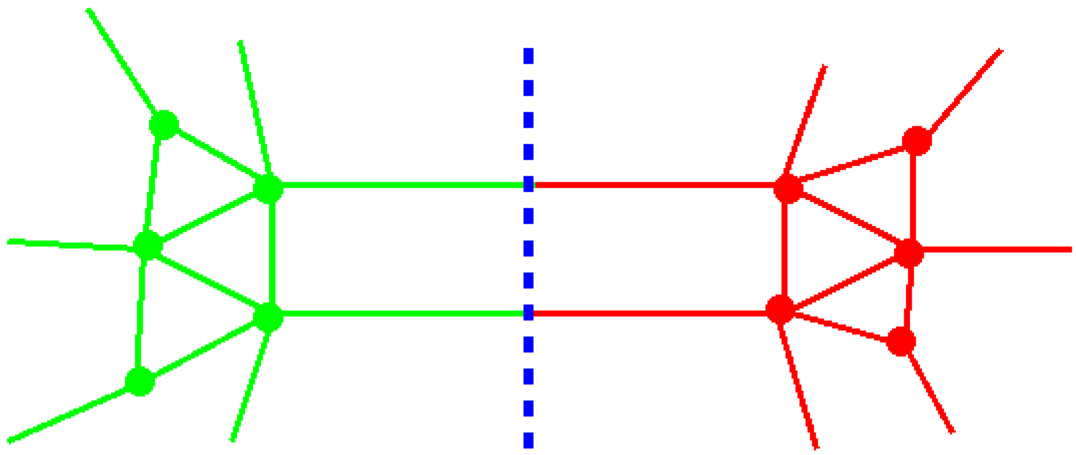


DSC Method and Partitioning

Graph partitioning: ParMETIS (University of Minnesota)

Goal:

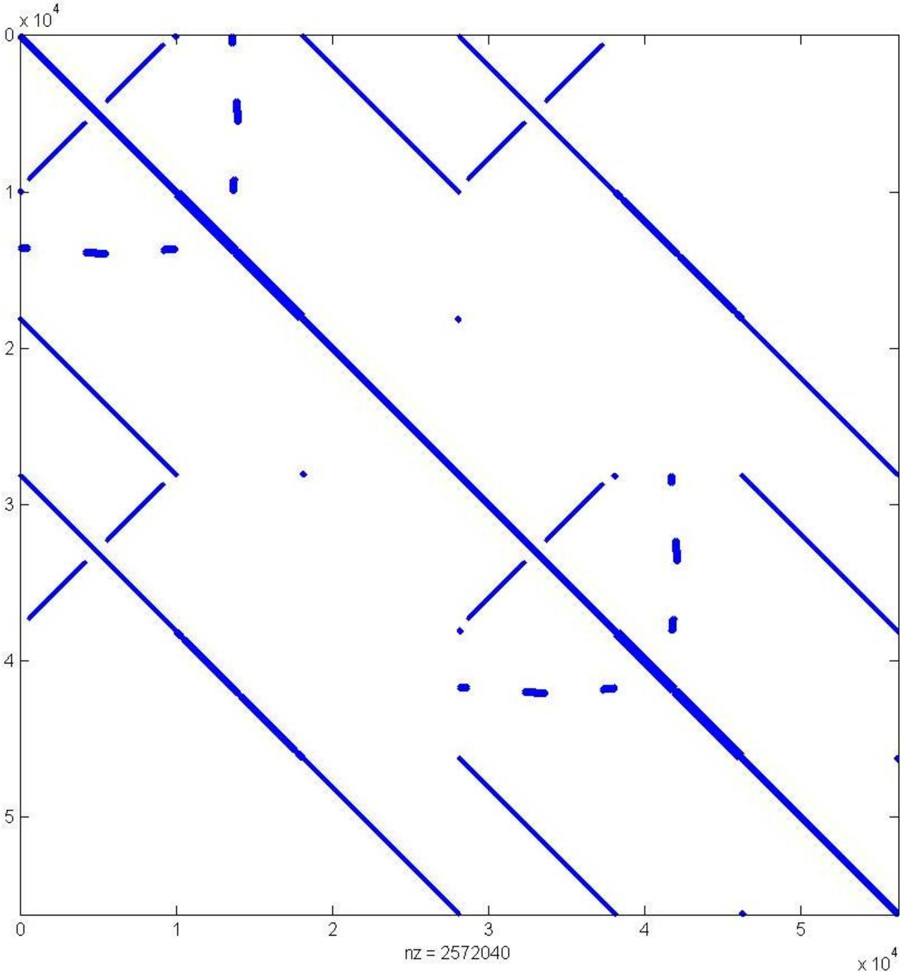
Minimize the number of edges cut ⟷ number of interface unknowns

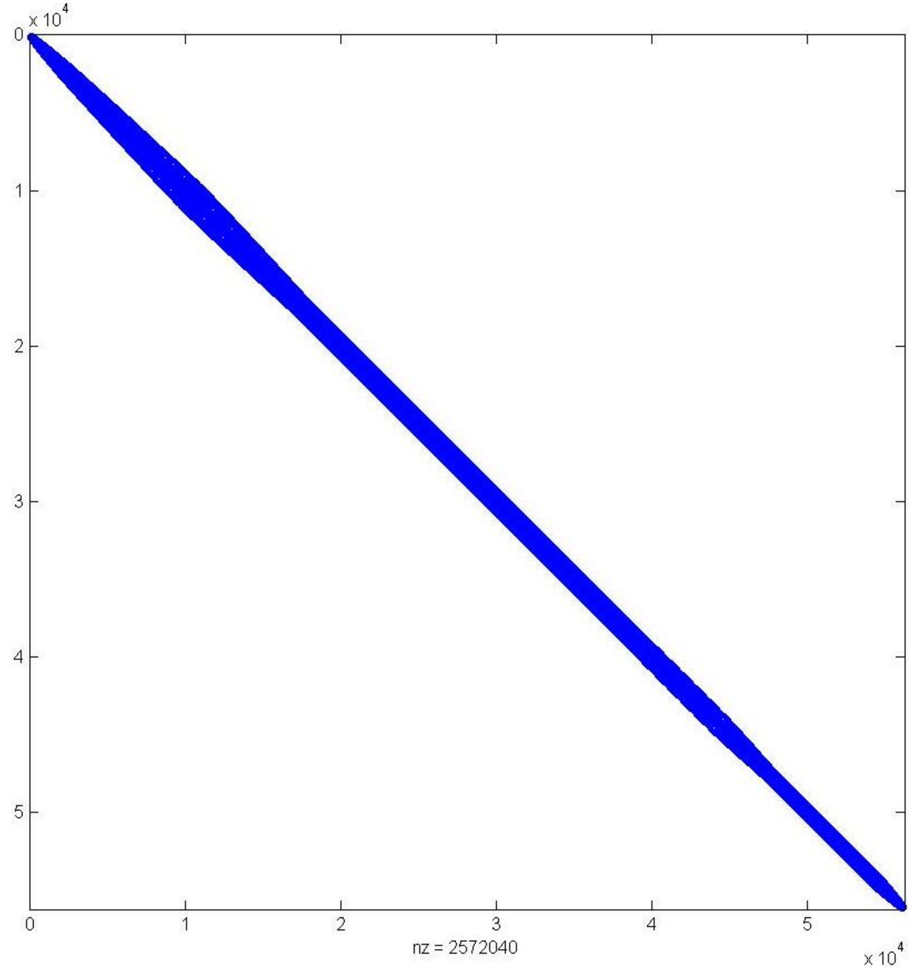


Matrix Permutation for Bandwidth Reduction

Original linearTRACE matrix problem:
n=56,240; nz=2,572,040; condition: $8.4 \cdot 10^6$

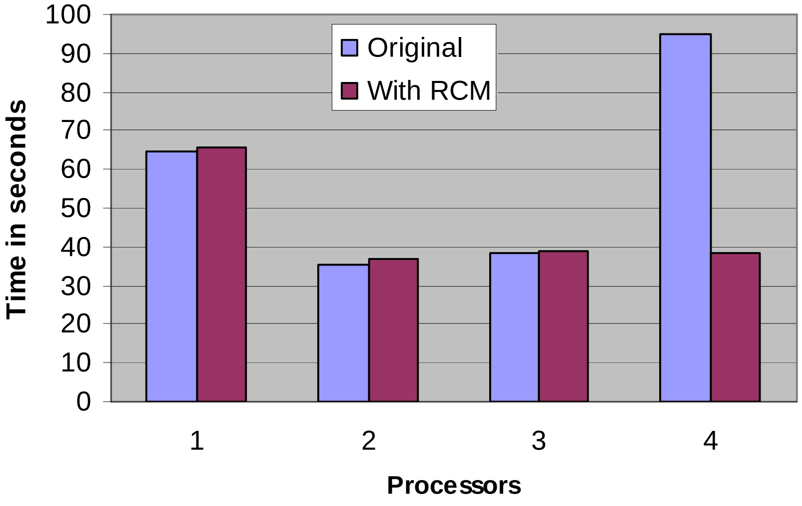
After *Reverse Cuthill-McKee* (RCM)

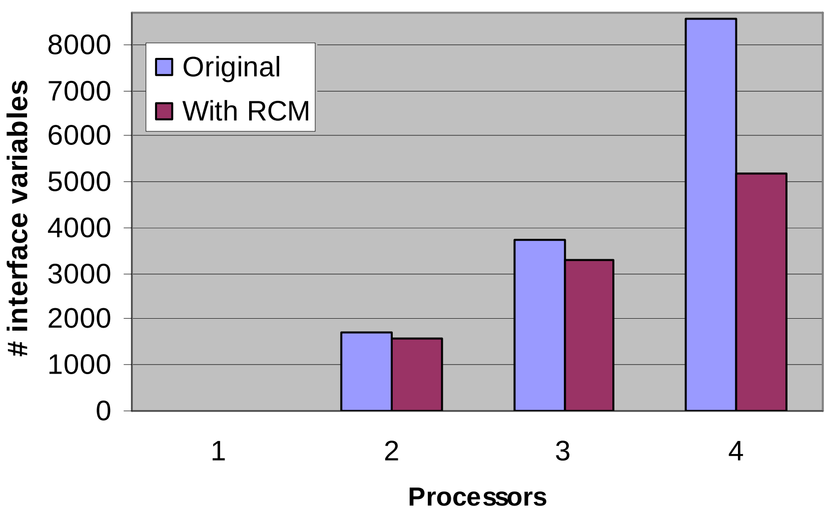




Performance Tests on a Quad-Core Intel Xeon CPU L5420

Comparison: DSC method for original and RCM permuted matrix

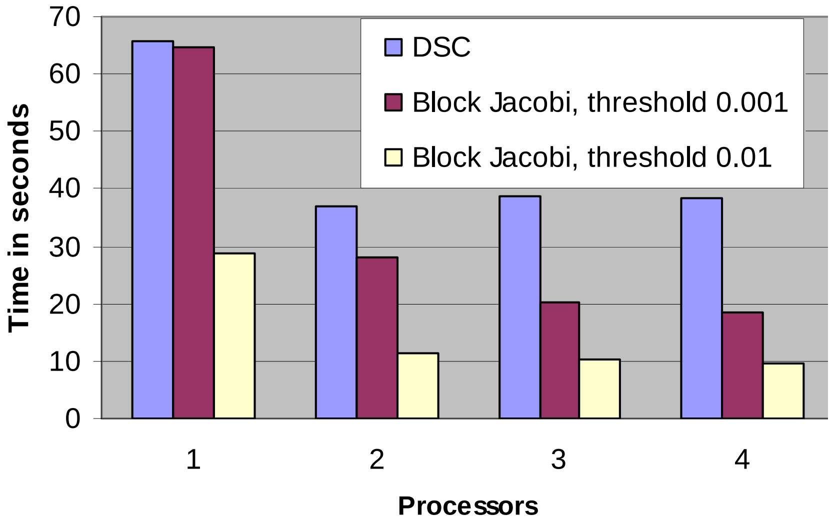


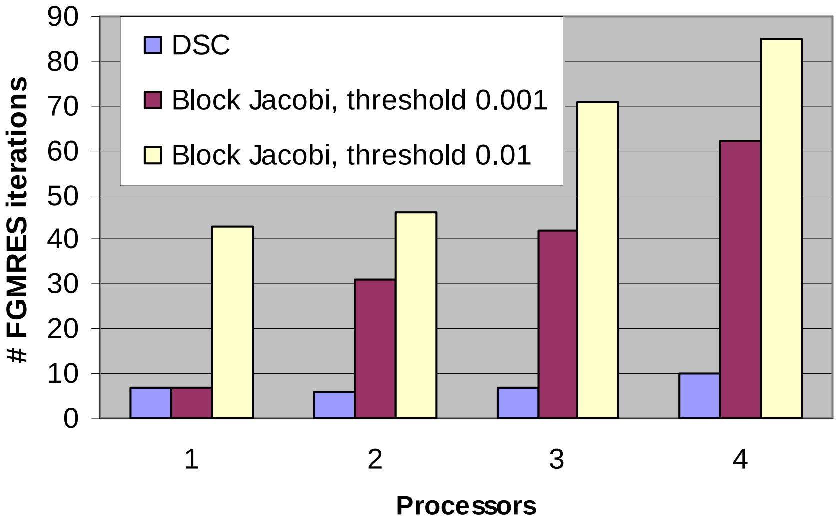


Number of interface variables is significantly lower with RCM.

Performance Tests on a Quad-Core Intel Xeon CPU L5420

Comparison: DSC method versus Block Jacobi preconditioning (with RCM)

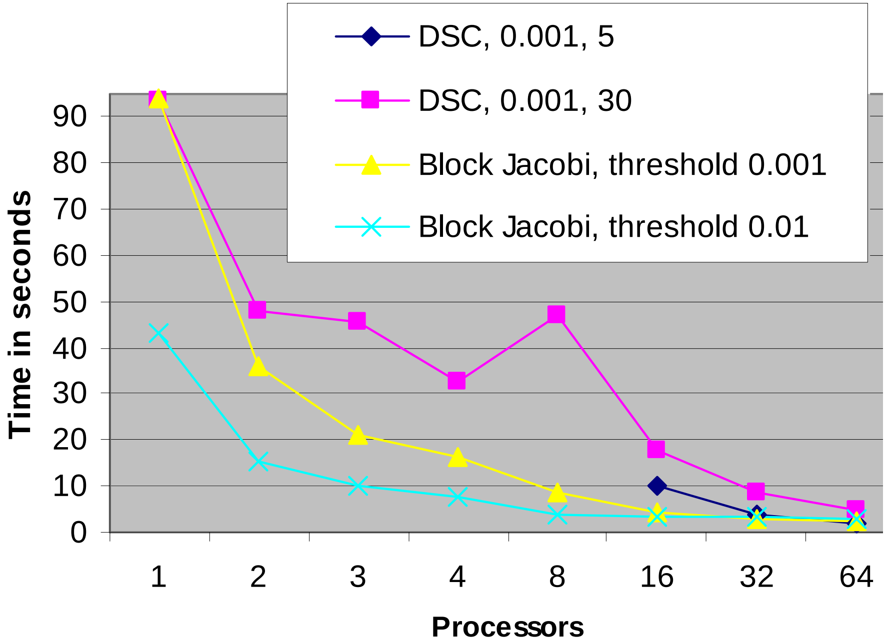


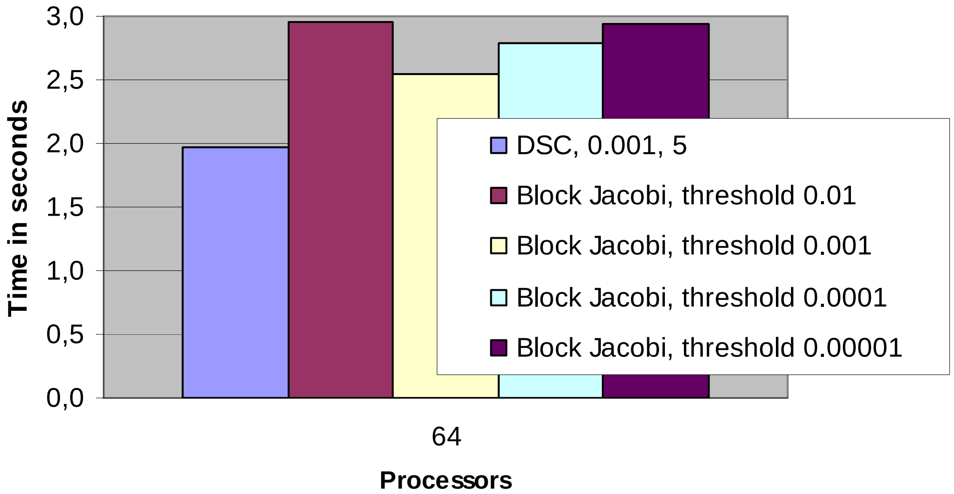


Number of iterations is stable for DSC, but Block Jacobi is faster.

Performance on a Cluster at DLR-AT
(AMD Opteron Processor 250; Dual-Processor Nodes; 2.4 GHz)

Comparison: DSC method versus Block Jacobi preconditioning (with RCM)





For a high processor count,
the DSC method appears to pay off.

Conclusions for TRACE Matrix Problems

- **Block Jacobi preconditioning performs well for small processor counts.**
- **The DSC method pays off for higher processor counts.**

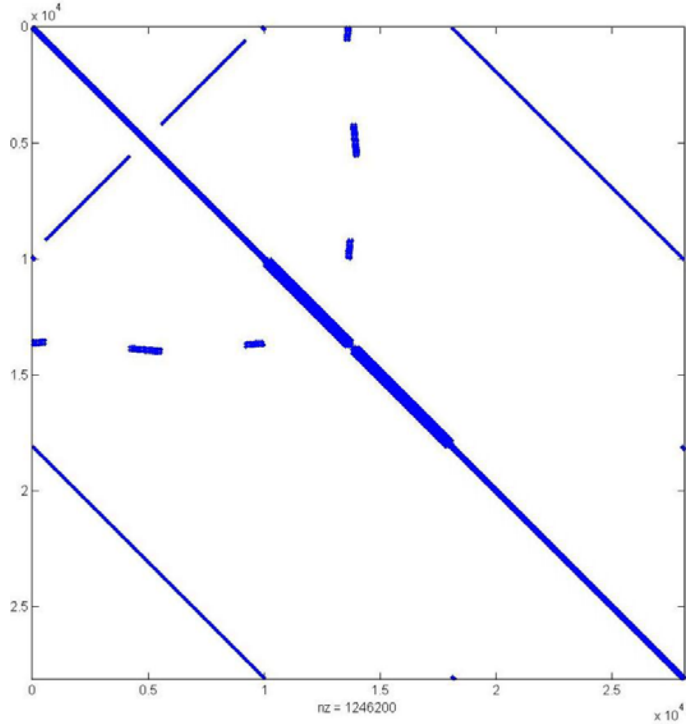
- **Potential method of choice: *intelligent* solver with**
  - **problem and convergence dependent parameter control;**
  - **problem and convergence dependent preconditioning;**
  - **preconditioning dependent on the processor count.**

Questions?

Typical linearTRACE Matrix Problem

Complex TRACE matrix
n=28,120; nz=1,246,200; condition: $6.7 \cdot 10^6$

$$Ax = b$$
$$\Leftrightarrow (C + iD)(y + iz) = c + id$$



Real TRACE matrix
n=56,240; nz=2,572,040; condition: $8.4 \cdot 10^6$

$$\begin{pmatrix} C & -D \\ D & C \end{pmatrix} \begin{pmatrix} y \\ z \end{pmatrix} = \begin{pmatrix} c \\ d \end{pmatrix}$$
$$\Leftrightarrow Gw = e$$